

AN ANALYSIS OF THE SENSITIVITY OF NON-URBAN ENVIRONMENTS TO RADIOACTIVE CONTAMINATION UNDER THE IAEA EMRAS-II PROGRAM

Tracy B.L.¹, Berkovskyy V.², Brittain J.E.³, Carini F.⁴, Chouhan S.⁵, Iosjpe M.⁶, Monte L.⁷ & Turcanu C.⁸.

¹Radiation Protection Bureau, Health Canada, Ottawa ON K1A 1C1, Canada, neutracy@rogers.com

²Division of Radiation, Transport & Waste Safety, International Atomic Energy Agency, Vienna, Austria

³ Freshwater Ecology & Inland Fisheries Laboratory (LFI), University of Oslo, Norway

⁴Institute of Agricultural and Environmental Chemistry, Università Cattolica del Sacro Cuore, Piacenza, Italy

⁵ Environmental Technologies Branch, Atomic Energy of Canada Limited, Chalk River, Ontario, K0J 1J0, Canada

⁶ Norwegian Radiation Protection Authority (NRPA), Oslo, Norway

⁷ ENEA, CR Casaccia, Via P Anguillarese 301, 00100 Rome, Italy

⁸Belgian Nuclear Research Centre SCK•CEN, Mol, Belgium

Since the early 1980s the International Atomic Energy Agency (IAEA) has led a succession of international programs to improve environmental transfer models for the assessment of radiological impacts on humans and non-human biota arising from radionuclides in the environment. These programs have included VAMP (Validation of Model Predictions), BIOMASS (BIOSphere Modelling and ASSESSment), and EMRAS (Environmental Modelling for Radiation Safety). The current EMRAS-II program (2009-2011) includes both routine and accidental emissions of artificial and natural radionuclides. This paper reports on the activities of Working Group 8 dealing with sensitive non-urban environments. First of all, the group has formulated a practical definition of environmental sensitivity. Then, in addition to conventional agricultural settings in the temperate zones, the group is studying special environments such as alpine, arctic, temperate forests, freshwater aquatic, and coastal marine environments. Initial modelling exercises are being carried out for depositions of the long-lived radionuclides ¹³⁷Cs and ⁹⁰Sr and the short-lived radionuclide ¹³¹I. Radionuclides concentrations are calculated in several environmental compartments, especially those leading to human exposures. Short term and long term radiation doses are calculated to the most exposed human populations. Some calculations are carried out with established codes; other are performed manually. The goal of these exercises is not just to compare different models but also to use these models as tools to investigate which environments, which components of each environment, and which seasons of the year would be most sensitive to a major release of radionuclides. The results will aid in the planning and implementation of emergency as well as long-term countermeasures (e.g., sheltering, food-bans, decontamination) following a nuclear accident.

Introduction

The objective of Working Group 8 of the EMRAS-II program is to explore the concept of environmental sensitivity in rural and semi-natural environments after an emergency situation. The main tasks of the working group are to:

- formulate the concept of environmental sensitivity;
- compile a list of sensitivity factors;
- design scenarios; and
- carry out modelling exercises based on these scenarios.

The results of these modelling exercises will be useful in emergency planning and preparedness by identifying sensitive areas and developing emergency response

plans appropriate to those areas. During the actual response to the emergency, the results will aid in setting priorities for the allocation of limited resources. The identification of vulnerable environments will be valuable in planning the locations of new nuclear facilities.

The concept environmental sensitivity could refer to the vulnerability of different ecosystems to one or more environmental stressors. However, for the purpose of this exercise, the term has been taken to refer to the impact of accidental radionuclide releases on human populations who depend upon different types of environments for their source of food. Given a release of radionuclides A into an environment B which impacts a human population C, *environmental sensitivity* describes the effect of the characteristics of B on the response of C.

Results of the modelling exercises

Modellers were instructed to carry out a modelling exercise in each of the following non-urban environments –agricultural, alpine, temperate forest, arctic, freshwater aquatic, coastal marine.

They were to assume a deposition of 1000 Bq/m² for each of the radionuclides ¹³⁷Cs, ⁹⁰Sr, and ¹³¹I. They were instructed to calculate concentrations in environmental media and food chain products leading to humans and to calculate the radiation doses to the most-affected human populations during first, second, and 10th year following the deposition.

Preliminary results are now available from the above modelling exercises. These results have not yet been refined through a careful intercomparison of the models, so the absolute magnitudes of the radiation doses should be considered with caution. Nonetheless, the preliminary results do provide some interesting insights on the differences between the environments and on the critical factors within each environment.

Agricultural (Canada and Europe)

Two models have been employed for the agricultural scenario . CHERPAC (CHalk river Environmental Research Pathways Analysis Code) is a time-dependent food-chain model which calculates stochastic ingestion, inhalation, immersion and groundshine doses for twenty-five radionuclides released to the atmosphere in accidental situations. It predicts best estimates, means, and 2.5% and 97.5% confidence limits of the output distributions. For terrestrial pathways, it starts with the daily values of either ground-level air concentrations and rainfall, or measured depositions. The outputs are human body burdens and concentrations in soil, forage, leafy and non-leafy vegetables, potatoes, other root crops, fruit, winter and spring grains, milk, cheese, beef, pork, eggs, poultry. CHERPAC also ranks the importance of the input parameters to variations in the output.

Figures 1a and 1b show CHERPAC results for radionuclides in crops and for doses to humans as a function of time after deposition. Concentrations are higher in pasture and leafy vegetables than in root vegetables initially, although the differences are less significant in the year following deposition. Ingestion doses are about two orders of magnitude higher than groundshine doses. Ingestion doses from the agricultural scenario were higher for infants than for adults or 10-year

olds in the first four months because dairy cows were assumed to be eating fresh grass, and milk reached the consumers faster than other food products.

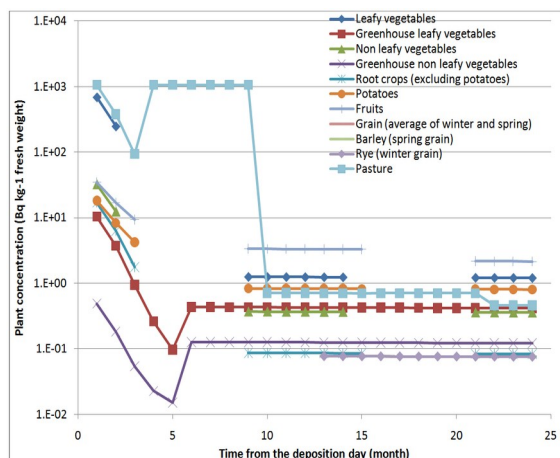


Fig. 1a. Cs-137 concentrations in vegetables after deposition.

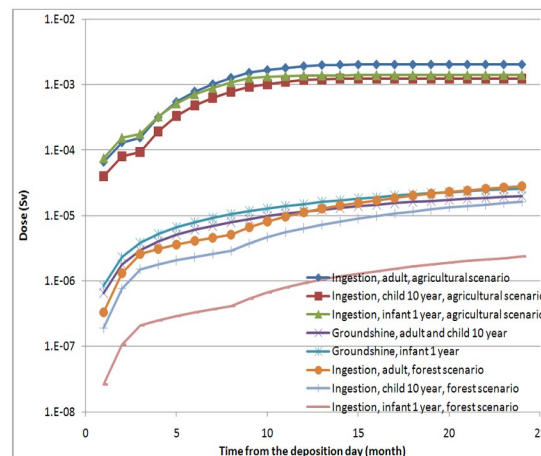


Fig. 1b. Doses as functions of time

The food chain and dose model (FDMT) of the decision support system JRODOS is appropriate for agricultural settings in the temperate zone. It estimates the transfer of radioactive material in food and feeding products and the doses from all relevant pathways (internal exposure via inhalation and ingestion, external exposure from the plume and from deposited radioactive material), similarly to the radioecological model ECOSYS. JRODOS/FDMT considers four types of soil (sand, loam, clay and peat). The contamination of plant products is based on foliar uptake, root uptake and resuspension, with consideration of translocation, weathering and growth dilution. Contamination of animal products is based on the activity intake of the animals (inhalation and contaminated feedstuff, including contaminated soil) and the kinetics of the radionuclides within the animals. Activity concentrations in up to 35 food products (raw or processed) can be calculated. JRODOS results for the concentration of radionuclides in a number of animal products are illustrated in Figures 2a and 2b. For the same amount of ground deposition, ^{137}Cs leads to higher activity concentrations than ^{90}Sr , which is especially evident in lamb meat. Figure 2b depicts effective ingestion doses due to ^{131}I , ^{90}Sr and ^{137}Cs for different age groups, calculated as a function of time for up to one year after deposition. In accordance also with the CHERPAC results, doses to infants tend to be highest.

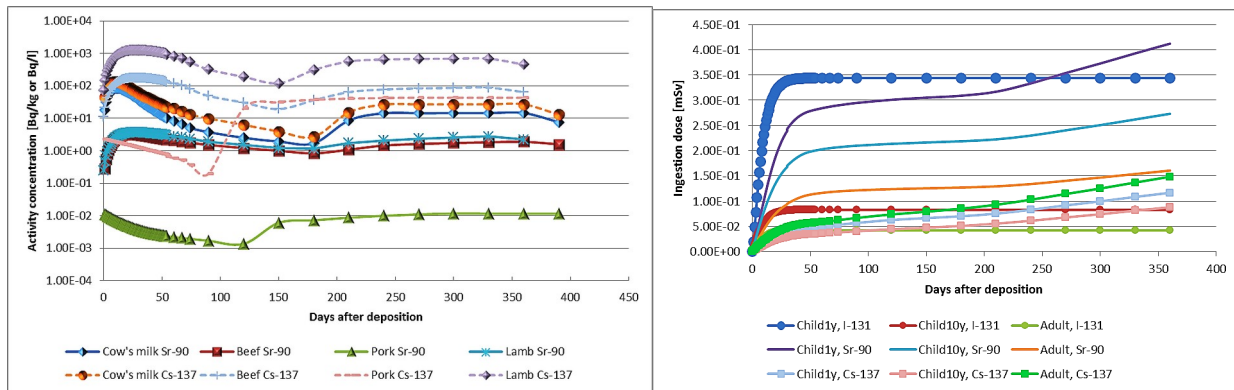


Fig. 2a Activity concentrations in animal products (log scale) Fig. 2b Ingestion doses

Temperate forest and Arctic scenarios. (Canada)

The CHERPAC model was extended to include wild berries, mushrooms, and small and large game in a forest scenario. As seen in Fig. 1b, the doses from the forest scenario are about two orders of magnitude lower than for the agricultural scenario. This is largely due to a much lower dependence on wild foods, even in a traditional hunting and food gathering society.

The temperate forest scenario was also modelled by Health Canada using the method of aggregated transfer coefficients, determined empirically by measuring radionuclide concentrations in animal meat or vegetables and comparing with known values of deposition. Health Canada also carried out more detailed calculations following the guidance of the Canadian Standards Association (2008). Although this document was intended primarily for calculating annual doses from routine radionuclide releases, it provides many equations that can be adapted to radionuclide transfer between environmental compartments under transient conditions. Dietary data for the temperate forest scenario was taken from a dietary survey of a northern Saskatchewan community. The country foods component of the diet assumed to make up 100% of the diet.

Results for the forest scenario are shown in Fig. 2a. The doses from ^{137}Cs are dominated by caribou, with wild berries also playing a significant role. Moose, small mammals, ground birds, and waterfowl all contribute about equally to the remainder of the ^{137}Cs dose. Mushrooms are not frequently eaten by Canadian aboriginal peoples, so they contribute very little to the dose. Health Canada also modelled the arctic scenario by the same methods as above. Dietary data were taken from Tracy and Kramer (2000) and from Indian and Northern Affairs Canada (2009). The results are shown in Fig. 2b. There is less variety of country foods in the arctic diet. Again, caribou dominate because of the importance of the lichen → caribou → human food chain.

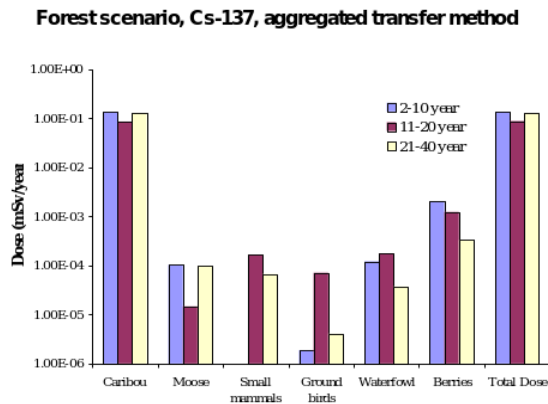


Fig 3a. Doses during the first year from ^{137}Cs from ^{137}Cs for various food items in the forest scenario.

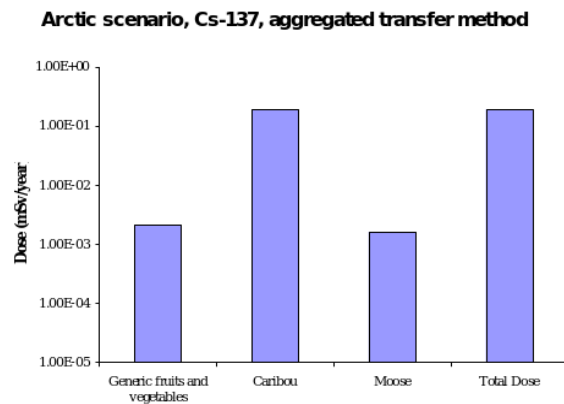


Fig. 3b. Doses during the first year for various food items in the

Freshwater aquatic scenario (Norway and Italy)

The MOIRA-PLUS application software (Monte et al., 2009) was used to assess radionuclide uptakes in two freshwater lakes -- Øvre Heimdalsvatn in Norway and Bracciano in Italy. MOIRA-PLUS allows one to make predictions for complex water body systems comprising lakes, reservoirs and rivers (MOIRA-RIVER). A specific code (MOIRA-PLUS LAKES) can be used to perform more detailed calculations for lacustrine systems. In particular, MOIRA-PLUS LAKES can evaluate the ecological impact of selected countermeasures on the basis of the so-called LEI (Lake Ecosystem Index). Due to the particular input-output structure of MOIRA-PLUS, it was assumed that the deposition occurred for a period of 1 month at constant rate. Model calibrations were performed using measured concentrations following the Chernobyl accident in order to determine the site-specific values of the transfer parameters controlling the migration of radionuclides through the abiotic and the biotic components of the two lakes. Demographic and food consumption data were obtained from the available literature (Strand et al., 1989) or from National Organizations (ISTAT- Istituto Nazionale di Statistica, Italy).

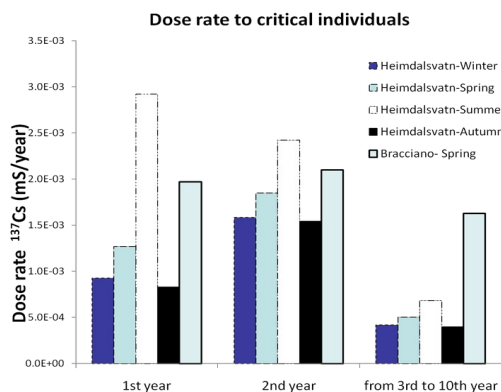


Fig. 4a. Doses from Cs-137 in Lake Heimdalsvatn.

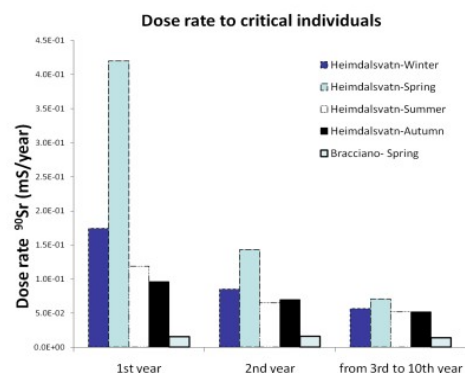


Fig. 4b. Doses from Sr-90 in

On account of the lower concentrations of K and Ca, activity concentrations in water and fish are much higher in Øvre Heimdalsvatn compared to Bracciano. However, the slow water renewal rate in Bracciano results in a very slow decline in radionuclide activity concentrations in fish, especially for ^{137}Cs . This is reflected in the doses for ^{137}Cs (Fig. 3a), although to a lesser extent for the more mobile ^{90}Sr (Fig. 3b).

Note that doses in summer dominate for ^{137}Cs whereas the spring dominates for ^{90}Sr . This is due mainly to the enhanced migration of the more mobile ^{90}Sr from the lake catchment during the ice melting period. On the contrary, ^{137}Cs , being less mobile due to its rapid fixation on the soil particles in the catchment, reaches higher concentrations in water when the deposition event occurs in summer while the lake is not covered by ice.

Coastal marine scenario

Calculations were carried out for six shallow marine coastal environments – Cumbrian waters of the Irish Sea, Lyme Bay on the English Channel, North Sea off the Norwegian coasts, Skarerrak, the Gulf of Riga on the Baltic Sea, and Ob Bay on the Kara Sea. The NRPA box model (Iosjpe et al., 2002) includes the processes of advection of radioactivity between water compartments, sedimentation, diffusion of radioactivity through pore water in sediments, resuspension, mixing due to bioturbation, particle mixing and a burial process for radionuclides in deep sediment layers. Radioactive decay is calculated for all compartments.

Radionuclide concentrations were calculated in fish, crustaceans, molluscs, and seaweeds. Consumption data were used to estimate doses to human populations.

The doses for the Cumbrian waters are shown in Fig 4 for the four radionuclides ^{131}I , ^{137}Cs , ^{90}Sr , and ^{239}Pu . The dose is critically dependent on radionuclide and food item.

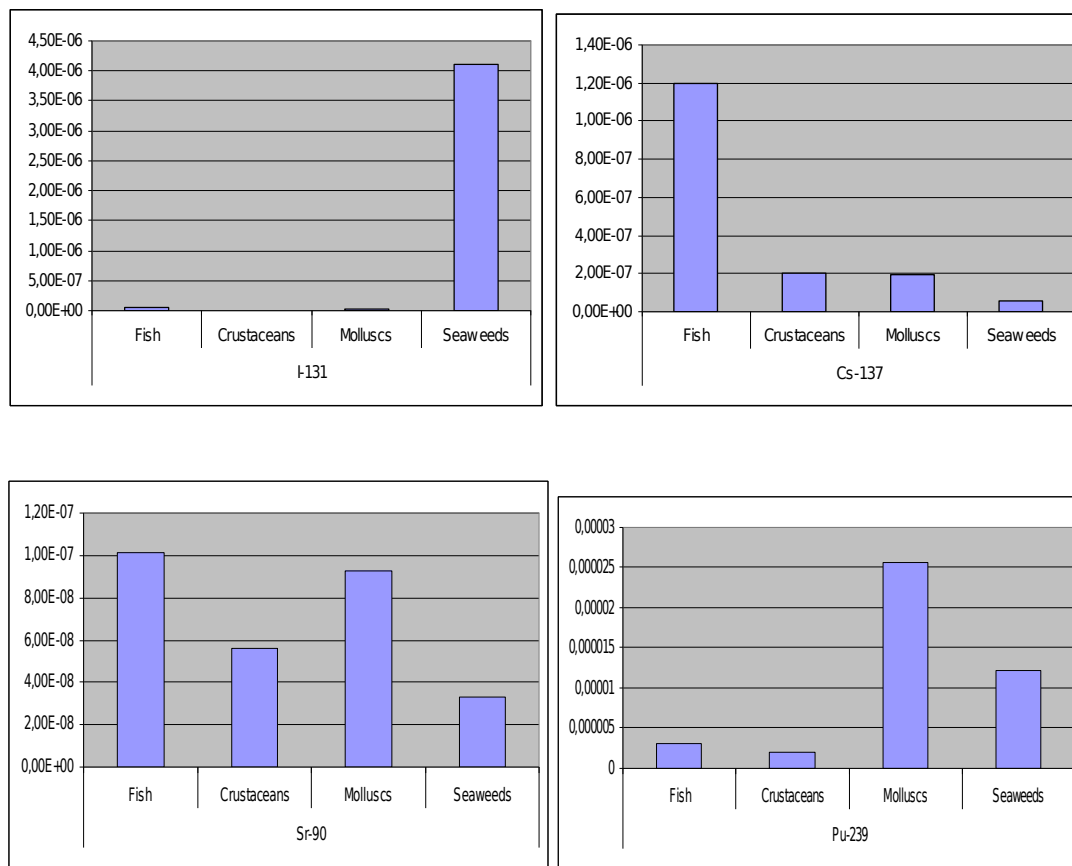


Fig. 5. Doses in Sieverts from one year of consumption of ^{131}I , ^{137}Cs , ^{90}Sr , and ^{239}Pu in fish, crustaceans, molluscs, and seaweed.

Note that the ^{131}I dose is totally dominated by seaweed consumption, whereas fish consumption is most important for ^{137}Cs . All four food items contribute more or less equally to the ^{90}Sr dose. The ^{239}Pu dose is dominated by molluscs. The highest doses were found for the Ob Bay location for the same sea food consumption for all coastal environments. Calculations show also that highest doses correspond to the first year following the deposition.

Comparison of different environments.

Table 1 shows preliminary dose estimates for the three radionuclides in the environments for which results are available. Agriculture provides the major source of food for nearly all peoples and thus has the largest doses in most cases. However, note that ^{137}Cs in the Arctic environment and ^{90}Sr in the lake scenarios can also produce significantly elevated doses. The doses in marine environments tend to be much lower, even in shallow coastal areas.

Table 1. Doses to adults (microsieverts per year) for different environments for ^{137}Cs , ^{90}Sr , and ^{131}I .

| Scenario | ^{137}Cs | ^{90}Sr | ^{131}I |
|--------------------------------|-------------------|------------------|------------------|
| Agricultural (Europe, RODOS) | 148 | 161 | 42 |
| Agricultural (Canada, CHERPAC) | 1931 | 288 | 467 |

| | | | |
|-------------------------------------|------|------|------|
| Forest (Canada, CHERPAC) | 23 | 0.50 | 0.51 |
| Forest (Canada, aggregate transfer) | 31 | 3 | 0.09 |
| Arctic (Canada, aggregate transfer) | 2050 | 1010 | 2.6 |
| Freshwater (Lake Heimdalsvatn) | 2.9 | 420 | ---- |
| Freshwater (Lake Bracciano) | 2 | 150 | ---- |
| Coastal Marine (Ob Bay) | 2.86 | 0.51 | 10 |

Conclusions

Following a nuclear accident, there can be wide variations in radiation doses to humans depending on the environment in which they live and from which they obtain their major food supply. The final report from this working group in 2012 will attempt to characterize these differences more precisely and to understand the factors in each environment contributing to the variations in sensitivity.

References

Canadian Standards Association 2008. Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities. CSA Standard N288.1. www.ShopCSA.ca

Indian and Northern Affairs Canada (2009). Canadian Arctic Contaminants Health Assessment Report.
<http://www.ainc-inac.gc.ca/nth/ct/ncp/pubs/har/har-eng.asp>

Iosjpe, M., J. Brown & P. Strand, 2002. Modified approach for box modeling of radiological consequences from releases into marine environment, J. Environ. Radioact., 2002, 60, 91–103.

Monte, L., 2009. Modelling the long-term behaviour of radiocaesium and radiostrontium in two Italian lakes
J Environ Radioact 80:105-23

Müller H., Gering F., Pröhl G. Model Description of the Terrestrial Food Chain and Dose Module
FDMT in RODOS PV6.0. RODOS(RA3)-TN(03)06.
http://www.rodos.fzk.de/Documents/Public/HandbookV6/Volume3/FDM_Terra.pdf

Strand, P., Bøe, E., Berteig, L., Berthelsen, T., Strand, T., Trygg, K., Harbitz, O., 1989. Whole-body counting and dietary surveys in Norway during the first year after the Chernobyl accident. Radiation Protection Dosimetry 27, 163-171.

Tracy B.L. and Kramer GH., 2000. A method for estimating caribou consumption by northern Canadians. Arctic
53:42-52.